

Effects of Frying Oil Composition on Potato Chip Stability

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Potato chips were fried in six canola (low-erucic acid rapeseed) oils under pilot-plant process settings that represented commercial conditions. Oil samples included an unmodified canola oil and oils with fatty acid compositions modified by mutation breeding or hydrogenation. Chips were fried for a 2-d, 18-h cycle for each oil. Chips and oil were sampled periodically for sensory, gas-chromatographic volatiles and chemical analyses. Unmodified canola oil produced chips with lower flavor stability and oxidative stability than the other oils. The hydrogenated oil imparted a typical hydrogenation flavor to the chips that slightly affected overall quality. The modified canola oil (IMC 129) with the highest oleic acid level (78%) had the lowest content of total polar compounds and the lowest total volatile compounds at most of the storage times; however, the sensory quality of the potato chip was only fair. The potato chip with the best flavor stability was fried in a modified/blended oil (IMC 01-4.5/129) with 68% oleic acid, 20% linoleic acid and 3% linolenic acid.

KEY WORDS: Canola, flavor, free fatty acid, frying, low-erucic acid, rapeseed, odor, polar compounds, potato chip, sensory, stability, volatile compounds.

Modifying the fatty acid composition of linolenate-containing oil to improve frying stability has previously focused on blending or hydrogenating oils to decrease the linolenic acid (1-3). More recently, genetic modification and breeding have been used to change the levels of the fatty acids (4). Researchers have shown that decreasing linolenic acid levels increased the stability of frying oils (5-7). Modification of other fatty acids has also been investigated (8-11). Oils bred to be high in oleic acid are commercially available, and plant breeders are now attempting to increase saturated fatty acids. The direction toward lower linolenic acid, higher oleic acid and higher saturates seems appropriate because oils with these fatty acid profiles have greater frying stability as judged by less oxidation, polymerization and hydrolysis. However, a major question to be answered is how these fatty acid composition changes affect the flavor of foods fried in the modified oils. Cottonseed oil, with its high (52%) level of linoleic acid, is considered to be the industry standard for producing food with desirable fried-food flavor. This flavor may be partly derived from the formation of 2,4-decadienal during the thermal oxidation of linoleic acid. On the other hand, foods such as potato chips that are fried in high linoleate-containing oils are not oxidatively stable (12). Because potato chips accounted for 32.5% of the total dollars spent in 1990 on snack foods (13), the type of oil used to fry chips is a major concern. Research has been conducted on alternative oils (instead of cottonseed) for potato chips (11,12). Previous papers (9,11) documenting the sensory analyses of potato chips produced from high-oleic oils reported only on the development of rancid flavor. Although this flavor is important in the sensory analysis of stability, the characteristic flavors imparted to foods that are fresh

or slightly oxidized—but not rancid—are probably of greater interest.

Finally, the practice of oil conditioning prior to frying foods is well known in the oil industry; however, this phenomenon is not well documented in the scientific literature. Therefore, a study of effects of time of oil use on quality and stability of fried food would be of interest. The first objective of this research was to investigate the effects of frying time on the quality and stability of frying oil and potato chips. The second objective was to determine effects of oil composition on the stability of the frying oil and chips and on flavor characteristics of the chips.

METHODS AND MATERIALS

Potatoes. Monona variety potatoes stored for seven months at 9°C and 93-95% relative humidity were used after a final storage hold at 13°C for one week. Specific gravity of the potatoes was determined (14). Tubers were cut into 0.15-cm thick slices by a rotary slicer (Knott Machine Co., Shaw, MA), and the slices were washed and dewatered prior to frying. Potatoes were chipped continuously at a rate of 27 kg of whole raw tubers per hour.

Oils. Refined, bleached and deodorized (RBD) canola oil (CAO) (low-erucic acid rapeseed oil) and refined, bleached, hydrogenated, deodorized canola oil (Hyd Canola) were obtained from a commercial oil processor. Three samples of CAO (IMC 01-4.5, IMC 01-3 and IMC 129), modified by mutation breeding, were received from InterMountain Canola (Cinnaminson, NJ) as RBD oils. A fourth sample of oil with modified composition was prepared by blending IMC 01-4.5 and IMC 129 (75:25). All oils contained citric acid as the only additive.

Potato chip frying. Potato chips were fried over a two-day period (Fig. 1). On day 1, 106 L of oil were pumped into the continuous chip fryer (Heat & Control Inc., San Francisco, CA). The oil reached frying temperature (192°C) in approximately 30 min. Chips were fried for 130 s at temperatures ranging from 192°C (inlet) to 187°C (outlet). At the end of 9 h of frying on day 1, the oil was cooled and pumped into a holding tank overnight. On day 2, the oil was pumped back into the fryer, and the heating/frying cycle was continued for another 9 h. Make-up oil was added periodically to maintain the 106-L oil level. Complete turnover of oil was achieved between 12 and 15 h on day 2 by a combination of removing oil and adding fresh oil.

Oil and chip sampling procedures. Oil samples were collected from the fryer at 3, 6 and 9 h of frying on day 1 and after 12, 15 and 18 h on day 2 (Fig. 1). Oil was also taken from the fryer before heating began on both days 1 and 2, as well as after the oil had reached frying temperature on both days but before frying started. Chips were sampled eight times during the frying process (Fig. 1).

Instrumental and chemical analyses of oils and chips. The percent polar compounds was determined in duplicate by the Association of Official Analytical Chemists column chromatography method (15). Free fatty acid (FFA) content was measured in duplicate by the American Oil

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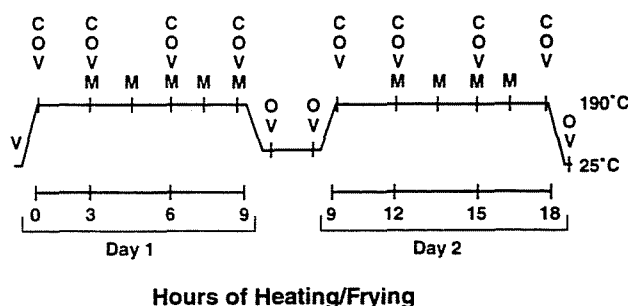


FIG. 1. Flow chart for frying chips and for sampling of chips, oils and volatile compounds. C, chip sample taken; O, oil sample taken; V, volatile sample taken (headspace above fryer enclosure); M, make-up oil added.

Chemists' Society method (Ca 5a-40) (16). Chip moisture content was monitored with an infrared moisture meter (Ohaus Moisture Balance 601C; Ohaus, Florham Park, NJ) with the lamp set at 140 W, 2.5 cm above a 10-g sample of crushed chips. Finished chip color was evaluated on an Agtron spectrophotometer (Model M-300; Magnuson Engineering Inc., San Jose, CA) with red mode setting and calibrated with 00 and 90 disks (17).

Chip packaging and storage. Portions of chips (5–300 g) from each sampling period were placed in metalized foil bags and sealed. Chips for initial sensory and volatile compound analyses were taken from sealed bags. The remaining sealed bags of chips were aged under ambient conditions at 25°C.

Gas-chromatographic volatile compound analysis. Volatile compounds in the fresh and aged chips were analyzed by using a Perkin-Elmer 8320 capillary gas chromatograph (GC) equipped with a flame-ionization detector (FID) and fitted with a headspace analyzer (Model HS-6; Perkin-Elmer Co., Oak Brook, IL). One-gram portions of ground chips were placed in 6-mL headspace vials and sealed with a Teflon-lined septum and aluminum cap. Each vial was placed in the headspace analyzer and heated to 130°C for 10 min to generate volatiles. Samples were run in triplicate. Volatiles were collected at the head of the column (DB-5 fused-silica capillary, 30 m × 0.32 mm, 1 micron film thickness; J&W Scientific, Rancho Cordova, CA), held at 0°C, and were automatically injected after an initial hold of 5 min. Column temperature was programmed from 0 to 240°C at 20°C/min with a final hold of 5 min. Other GC conditions were: injector temperature, 200°C; detector temperature, 250°C; carrier gas, helium at flow rate of 1 mL/min at 10 psi. Volatile compounds were identified by matching retention times with those of authentic compounds.

Volatile compounds formed during frying of potato chips were collected from an enclosure over the fryer with a 2-mL A-2 gas sampling syringe (Precision Sampling Corp., Baton Rouge, LA). The sample was injected directly into the injector port of a capillary GC (Hewlett-Packard 5890; Hewlett-Packard, Palo Alto, CA) equipped with an FID and fitted with an SPB-5 capillary column (Supelco, Bellefonte, PA). Other conditions included: carrier gas, helium at 1 mL/min at 8 psi; column temperature, 0–240°C at 20°C/min; detector temperature, 250°C; injector temperature, 200°C.

Fatty acid composition. Compositions of the initial oils were determined by capillary GC analysis with a Varian 3400 GC (Palo Alto, CA) equipped with an SP2380 column (30 m, 0.25 mm i.d., 0.20 micron film thickness; Supelco). Column temperature was held at 170°C for 10 min, and temperature was programmed to 220°C at 3°C/min. Other GC conditions were injector, 240°C; detector, 280°C.

Sensory analysis. A 15-member trained, experienced analytical sensory panel evaluated the potato chips for overall quality on a 10-point scale (10 = excellent quality and 1 = bad quality). The panelists also rated the chips for individual flavor intensities on a 10-point intensity scale (0 = no flavor, 10 = strong flavor). Analyses were conducted under red light to mask any color differences in the chips.

Statistical analysis. Data were evaluated with analysis of variance (18). Statistical significance was expressed at $P < 0.05$ unless otherwise indicated.

RESULTS AND DISCUSSION

The average specific gravity (weight-in-air/weight-in-water) of the potatoes ranged from 1.078 to 1.089 at the time of the fry tests. Moisture content ranged from 1.0 to 1.3% for chips fried in all oil types. The color of the chips was lighter the first day of frying than the second day. Agtron units varied among oils from 53 to 57 on day 1 and from 49 to 52 on day 2 (data not shown).

Fatty acid composition. The fatty acid composition of the six oils showed a range in iodine values (IV) from 108.8 for unmodified CAO to 86.0 for the hydrogenated oil (Table 1). Modified oils IMC 01-4.5, IMC 01-3 and IMC 01-4.5/129 had higher oleic acid and lower linolenic acid (Ln) levels than the CAO. Sample IMC 129 had higher levels of C18:1 (78%) and lower amounts of C18:2 (8.5%) than the other modified oils. The hydrogenated oil had only 0.8% Ln.

Oil stability tests. Polymerization and hydrolysis of the frying oils were measured by total polar compounds and FFA. FFA level increased with increasing C18:1 content, with the exception of the hydrogenated oil sample (Table 2). Unmodified CAO had the lowest FFA level (0.19) after 18 h of oil use, whereas sample IMC 129 had the highest content of FFA at 0.27. All FFA values were significantly different from one another after 18 h of use, with the exceptions of IMC 01-4.5 and hydrogenated CAO.

After 18 h of oil use, total polar compounds in the frying oils ranged from 7.8 to 10.3 (Table 3). Oil IMC 129, with the highest percent oleic acid content, had the lowest level of total polar compounds (7.8%) and was not significantly different from oils IMC 01-3 and IMC 01-4.5/129. The two highest levels of polar compounds were measured in the hydrogenated sample (10.3%) and in IMC 01-4.5 (9.7%).

Volatile compounds in potato chips. Compounds collected within the fryer enclosure showed a pattern of significant increases and decreases depending on sampling time (Fig. 2, top panel). Complete data were available for only four of the six oils used for frying and showed initially high levels of volatile compound formation as oil reached frying temperature. The amount of compounds in all oils had decreased significantly at the 3-h. At the 6 and 9 h, the levels continued to decrease slightly from the 3-h time period, with the exception of the hydro-

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TABLE 1

Fatty Acid Composition of Canola Oils^a

Fatty acids	Canola	IMC 01-4.5	IMC 01-3	IMC 129	IMC 01-4.5/129	Hyd Canola
C16:0	4.2	4.0	4.0	3.5	3.8	4.8
C18:0	2.0	2.3	2.4	2.3	2.3	5.5
C18:1- <i>cis</i>	61.9	64.2	66.8	78.3	68.4	57.4
C18:1- <i>trans</i>						16.7
C18:2- <i>cis</i>	20.6	23.6	21.3	8.5	19.7	11.3
C18:2- <i>trans</i>						0.4
C18:3	7.7	2.8	2.9	4.2	3.1	0.8
Other	2.3	2.0	1.8	2.1	1.9	1.9
Iodine value	108.8	103.1	101.6	93.0	100.8	86.0

^aHyd Canola, refined, bleached, hydrogenated, deodorized canola oil. IMC 01-4.5, IMC 01-3, IMC 129 (InterMountain Canada, Cinnaminson, NJ).

TABLE 2

Free Fatty Acids (% oleic) in Canola Oils Used for Potato Chip Frying^a

Oil use (h)	Canola	IMC 01-4.5	IMC 01-3	IMC 129	IMC 01-4.5/129	Hyd Canola
0 h						
Day 1	0.09	0.09	0.09	0.09	0.09	0.09
9 h						
Day 2	0.14	0.13	0.15	0.17	0.16	0.15
18 h						
Day 2	0.19	0.21	0.25	0.27	0.23	0.21

^aSee Table 1 footnote.

TABLE 3

% Total Polar Compounds in Canola Oils Used for Potato Chip Frying^a

Oil use (h)	Canola	IMC 01-4.5	IMC 01-3	IMC 129	IMC 01-4.5/129	Hyd Canola
0 h						
Day 1	3.8	4.0	3.3	3.6	4.6	3.5
9 h						
Day 2	6.5	6.3	6.2	5.5	6.4	7.7
18 h						
Day 2	8.9	9.7	8.3	7.8	8.6	10.3

^aSee Table 1 footnote.

generated sample. However, after the oils had been cooled overnight, then reheated on day 2, the levels of volatile compounds increased significantly from the last sampling time on day 1. The same decrease at subsequent sampling times of 12, 15 and 18 h then repeated on day 2 as on day 1. A similar pattern of volatile compound level variation was measured in some of the fresh chips (Fig. 2, middle panel) as collected above the fryer enclosure. However, only two oil types, IMC 01-4.5 and CAO, showed the same initial high level followed by a decrease at subsequent sampling times on day 1. These two oils had the lowest amounts of saturates and monounsaturates. The four oils with the lowest IV—IMC 129, IMC 01-3, IMC 01-4.5/129 and Hyd Canola—all had lower initial volatile compound levels, followed by a significant increase at 3 h. All oil types showed a significant increase in compounds at the start of frying on day 2 as compared to the levels at the end of day 1. Canola oil showed the widest fluctuations in volatile compound levels over the frying cycle with a significantly higher level at the start of frying on day 2 than the other oils. The volatile compound levels in the aged (four month) chips (Fig. 2, bottom panel) had patterns of changes more similar to the patterns noted in Figure 2 (top panel) for the fryer enclosure than for the fresh chips (Fig. 2, middle panel). Chips fried in IMC 129—the highest oleic acid-containing oil—and then aged

had the least amount of volatile compound formation at three of the four sampling times. Chips fried in CAO had significantly more volatile compounds after four months of storage than chips fried in the other oils at all sampling times, except for 0 h on day 1.

Sensory analysis of chips. The flavor quality of the fresh, unaged chips (0 Time) showed a similar pattern of changes over the frying cycle (Fig. 3, top panel) as for volatile compounds (Fig. 2, middle panel). Chips fried in oil used for 3 or 6 h had higher flavor quality than chips fried in fresh oil. Also, the quality of the chips fried at the beginning of day 2 at 9 h showed lower quality scores than at the end of day 1, corresponding to the changes in volatile compounds (Fig. 2, middle panel). The process of cooling oil and holding it overnight may require extra preventive measures to inhibit oxidation of the oil that significantly affects potato chip quality. Chips fried in unmodified CAO had lower flavor quality scores than any of the modified oils, beginning at the 9-h sampling time on day 1 though the end of frying on day 2. The highest flavor quality ratings were given to chips fried in the blended oil IMC 01-4.5/129, IMC 01-3 and hydrogenated oil. The IMC 129 oil, with the lowest total polar compounds, did not have the best flavor quality scores but showed the least fluctuations in flavor quality over frying time.

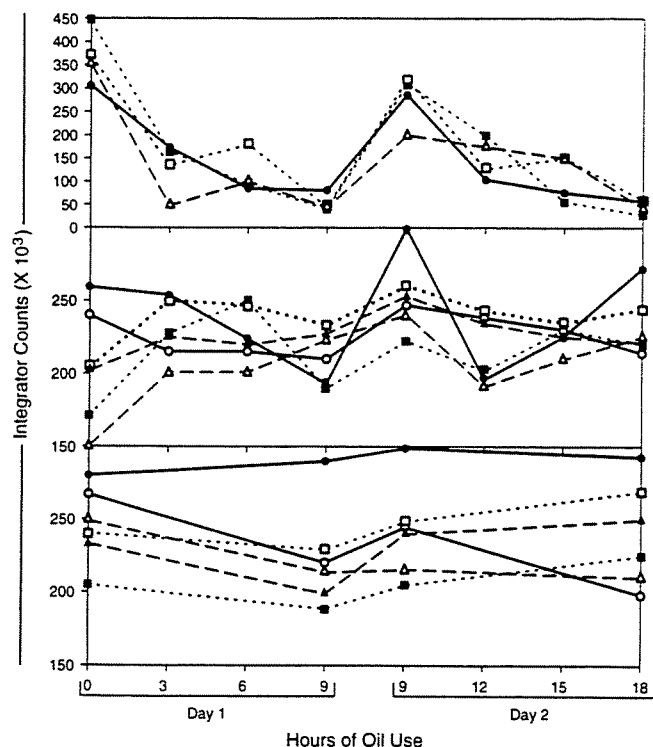


FIG. 2. Total volatile compounds in fryer enclosure (top panel) total volatile compounds in fresh potato chips (middle panel) and total volatile compounds in aged potato chips (bottom panel); ●, canola; ○, IMC 01-4.5; ▲, IMC 01-3; ■, IMC 129; △, IMC 01-4.5/129; □, hydrogenated canola.

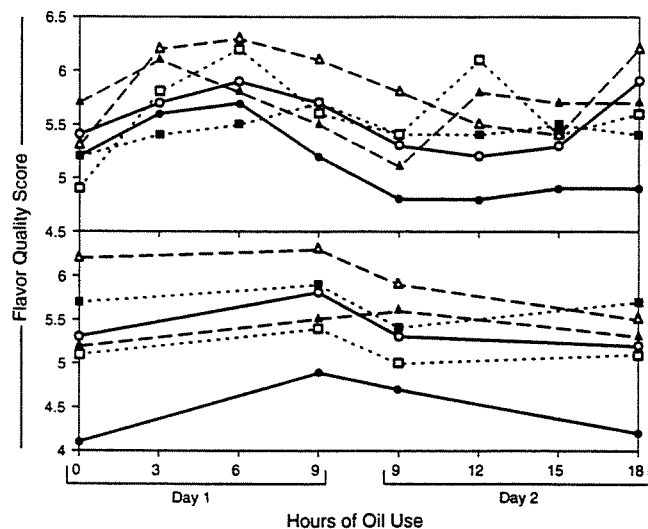


FIG. 3. Quality scores of fresh potato chips (top panel) and quality scores of aged potato chips (bottom panel); 10, excellent; 1, bad; Key as in Figure 2.

Storage of the chips at 25°C for four months showed a similar pattern of changes in quality (Fig. 3, bottom panel) over the frying cycle as seen for the fluctuations for fresh chips (Fig. 3, top panel). The chips with the lowest quality were fried in unmodified CAO, whereas the chips

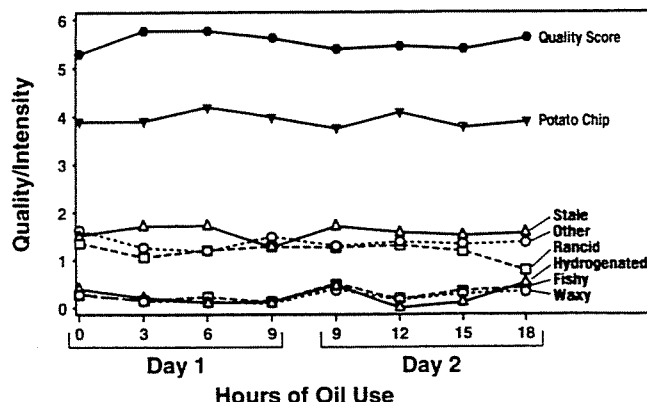


FIG. 4. Pooled flavor intensity scores and overall quality scores for fresh (0 time) potato chips fried in all oil types (quality scores: 10, excellent; 1, bad; intensity scores: 10, strong; 0, none).

with the best quality were fried in IMC 01-4.5/129 or IMC 129.

The fluctuations in overall quality scores pooled over all oil types showed the initially lower quality of chips fried in fresh oil, followed by an increase in quality for 3-h chips and a decrease in scores at the beginning of frying on day 2 (Fig. 4). The potato chip flavor had the greatest impact on overall quality, as shown by the same pattern of increases and decreases as overall quality. Other flavors, such as stale, rancid, waxy, fishy and hydrogenated, detected in fresh chips, had much less effect on quality than the potato chip flavor (Fig. 4). These other flavors also increased and decreased, depending on time of sampling in the fry cycle.

The initial fatty acid composition of the oils significantly affected the overall flavor quality scores of the chips (Fig. 5). As the Ln content increased from 0.8 to 7.7, the quality score decreased linearly, with the exception of sample IMC 01-4.5/129 (Fig. 5). The relationship of C18:2 to overall flavor quality was not linear (Fig. 5). The higher C18:3 content of the unmodified CAO had a greater effect on the quality than did the amount of linoleic acid. The plot of the quality scores vs. the oleic acid content fit a parabolic curve (Fig. 5). It appears that there may be an optimum amount of C18:1, and too little or too much oleic acid may contribute to decreased quality.

The plot of fatty acid composition vs. three flavor descriptors may help explain the variations in flavor quality (Fig. 6). As the percent of Ln increased above 3%, the fishy flavor intensity increased significantly (Fig. 6). The intensity of potato chip flavor increased significantly with increasing C18:2, with the exceptions of the Hyd Canola and CAO samples (Fig. 6). The off-flavors (hydrogenated in the Hyd Canola oil and fishy in CAO) probably masked the potato chip flavor. Finally, the waxy flavor showed a significant change along with the increases in C18:1 level (Fig. 6). The CAO with 62% oleic acid had the lowest waxy flavor intensity, and the hydrogenated oil had the highest intensity. Based on these observations, there may be minimum and maximum levels of various fatty acids specified for potato chip frying. To minimize the fishy flavor, a maximum of 3% Ln may be appropriate. The level of linoleic acid should not be too low or the fried food

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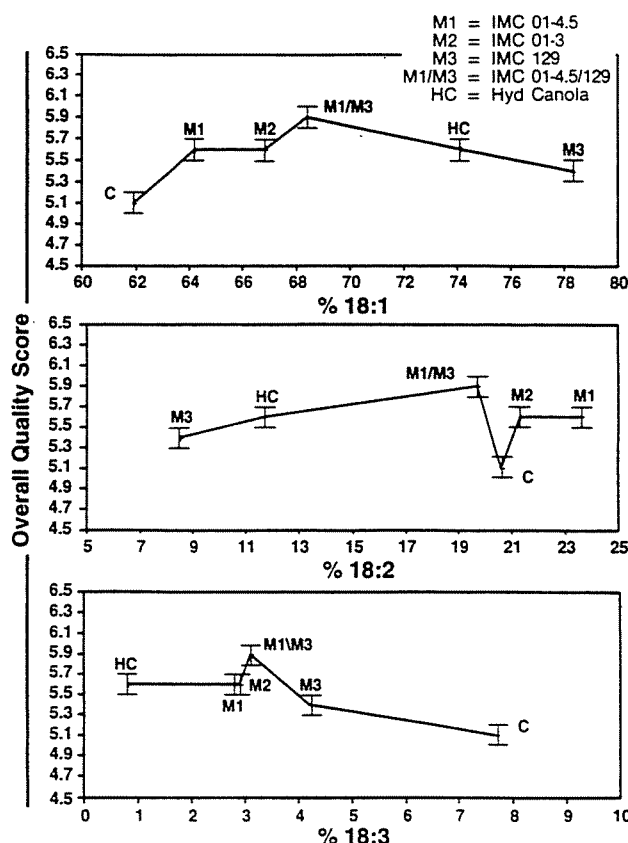


FIG. 5. Effect of fatty acid composition on overall quality scores of potato chips (0 time pooled scores); 10, excellent; 1, bad.

flavor intensity may be adversely affected. In this study, the oil with 19% C18:2 had the best potato chip flavor. Finally, even though increasing oleic acid levels increased frying stability (Table 3), C18:1 contributed to a waxy off-flavor that negatively affected potato chip quality.

This study showed that the chips fried in fresh oil had lower flavor quality than chips fried in oil conditioned (heated) for 3–6 h. Unmodified CAO produced chips with lower quality and poorer stability than did the modified oils. The hydrogenated oil imparted a typical hydrogenation flavor to the chips that slightly affected overall quality. The modified CAO with the highest oleic acid level (IMC 129) had the lowest content of total polar compounds and the lowest total volatile compounds; however, the initial potato chip quality was not the best, although this sample did have the best flavor stability after the most severe testing (18-h oil and aged four months at 25°C). Potato chips fried in a modified/blended oil (IMC 01-4.5/129) with 68% oleic acid, 20% linoleic acid and only 3% Ln had higher flavor quality and stability more often than any of the other oils.

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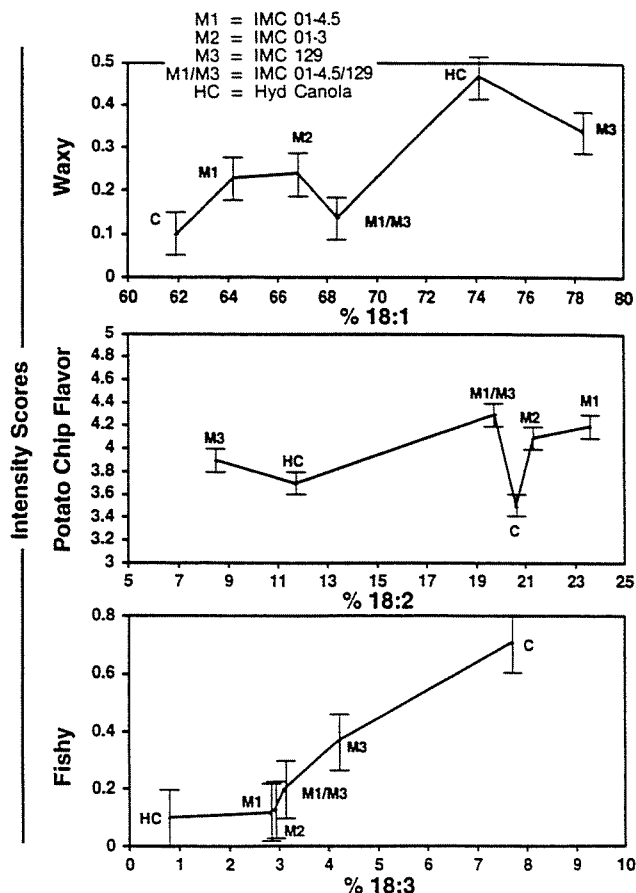


FIG. 6. Effect of fatty acid composition on flavor intensities of potato chips (0 time pooled scores); 10, strong; 0, none.

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